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Thesis

PRESENT PRACTICE AND OPINION IN THE TEACHING OF PHYSICS IN THE PUBLIC HIGH SCHOOLS OF THE UNITED STATES

Submitted by

John Burgess Coleman
(S.B.,M.I.T. 1926)
(S.M.,M.I.T. 1927)

In partial fulfillment of the requirements for the
degree of Master of Education.

1934.

First reader - Dr. Jesse B. Davis, Professor of Education
Second reader - Edward J. Eaton, Professor of Education

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School of Education
Library

First reader: Dr. Jesse B. Davis, Professor of Education

Second reader: [illegible] Professor of [illegible]

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CHAPTER I.

INTRODUCTION.

1. THE PURPOSE OF THIS STUDY.

It is my purpose in this study to accomplish the following tasks:

1. To determine the trend in enrollment or popularity of Physics as a curriculum subject in the high schools of the United States.

2. To investigate the education, training, experience, and duties of teachers of Physics in the high schools of Massachusetts.

3. To determine the objectives of high school Physics courses, as expressed in courses of study and in statements of authorities.

4. To survey the literature on methods of teaching Physics in high schools, to determine present-day practice in regard to provision for individual differences, laboratory instruction, methods of testing, units, projects, prerequisite and correlated mathematics.

5. To suggest certain modifications in high school Physics courses in the light of present-day knowledge and opinion in regard to high school objectives, teaching methods, and the place of Physics in modern life.

The writer's experience as a student and teacher leads him to consider Physics as a subject having many peculiar difficulties, both at the secondary and at the college level. This opinion is confirmed by conversations with many students and teachers. These difficulties are due to the enormous scope and abstract nature of the subject, and the advanced mathematics which is often necessary to comprehend the material. The student's difficulties are

frequently increased by the fact that persons who have studied the field of Physics sufficiently to be considered competent to teach it, are often much more interested in the subject-matter than in the student as a personality. Advanced study of Physics tends to attract persons of high abstract intelligence, who are frequently deficient in social intelligence, "common sense", or "humanism".

There is little doubt that the field of Physics is rich in opportunities for promoting the well-being of its students, if only the proper methods of instruction be used. This is now realized by many educators, as will be shown below in the discussion of objectives and teaching methods.

2. DEFINITION OF PHYSICS.

Physics is probably the broadest of all fields of learning. The writer, after several years of study and experience in the application of physical principles to practical problems, defines it broadly as the study of matter and energy, and their interactions in time-space. It may also be expressed as the study of the three fundamental dimensions, length, mass, and time. These definitions are philosophical, and appear hopelessly abstract to one who has not spent many hours in reflection upon physical science. Such definitions are an example of the physical discussion which appears like mere nonsense to the layman, and which causes general unpopularity of the subject. Physics is, however, a philosophy. It reaches beyond the bounds of knowledge, into the realm of faith. The philosophical physicist, Dr. Eddington or Dr. Einstein, include in their studies everything, the cosmos, "the world and they that dwell therein."

More specifically, the field of Physics has for many years

been divided into a number of distinct subjects, all of which are discussed in elementary courses. These are:

Mechanics.
Heat.
Sound.
Light.
Magnetism and Electricity.

This is the usual classification found in textbooks of general Physics for high school and college use following the organization of the earliest texts with the exception of Astronomy, which is now considered as a separate subject. Some modern texts add a section on Electron Physics.

In addition to these traditional divisions of the subject, Physics now includes the following distinct topics:

Molecular and atomic nature of matter.

Electrochemistry, the study of the chemical effects of electricity.

Physical Chemistry, the study of solutions, speed of chemical reactions, energy transfer in reactions, etc.

Atomic Structure and Electron Physics.

Radiations, X-Rays, Radio-activity.

In addition to the bodies of theoretical knowledge included under these subjects, the whole vast field of Industrial Physics must be considered. Theoretical Physics is the foundation of all engineering enterprises; it is applied to nearly everything with which we come in daily contact. Modern Physics texts make considerable use of Industrial or Applied Physics in presenting theoretical knowledge through a practical approach.

3. BRIEF HISTORY OF PHYSICS TEACHING.

The history of Physics teaching in American secondary schools has been ably discussed by R.J.Rowland [1], and the material presented here has been drawn from his study.

The early American schools were dominated by religious influence; they were dedicated to the task of carrying on a theocratic society, and their programs of instruction consisted of fundamental tool subjects, Latin and Greek classics, and theology. The scientific movement of the seventeenth and eighteenth centuries did not come into educational prominence until the early 1800's. Natural Philosophy was taught in American universities before the Revolutionary War, but it was for many years subordinated to the classics. Sciences gradually became important university subjects, and during the middle decades of the nineteenth century a number of schools devoted entirely to theoretical and applied science and technology were founded. This movement was stimulated by government grants of land to agricultural and mechanical colleges under a Congressional Act of 1862.

The spread of science teaching among colleges influenced the secondary schools. The Latin Grammar School always denied it admission, but the Academy offered Natural Philosophy, including Physics, Chemistry, Astronomy, and a variety of courses in applied science, Navigation, Surveying, etc. The early science teaching in secondary schools was inspired by university science, but was organized independently. "It grew up as a felt need on

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[1] History and trend of the teaching of physics in the secondary schools of the United States. B.U.School of Ed. thesis. 1931.

the part of the public for a proper understanding of the rapidly advancing scientific era." [2]

The early method of teaching was by lectures, and by demonstrations with "philosophical apparatus". Experimental work in secondary school science was conducted from the beginning, but the instructor, not the students, performed the experiments. About 1870, high schools began to differentiate Physics and Chemistry. Physics was usually elective, and was not generally popular because it was not made interesting to the student. It was recognized that the student did not have sufficient contact with the subject-matter, and during the last quarter of the nineteenth century individual laboratory work and the inductive method were generally introduced.

As Physics became a customary offering of high schools, the universities gradually adopted it as a requirement for entrance. In 1886, Harvard established definite requirements of high school Physics courses, including individual laboratory work. These requirements were set forth in the Harvard Descriptive List published in 1887, and served as a model for many other universities in establishing requirements in Physics. The universities were now largely shaping secondary school Physics in two ways; the textbooks were generally written by university professors and were frequently merely abridgements of the college texts; the universities made definite requirements for Physics as an entrance subject.

The universities had a further influence through their

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[2] Rowland, op.cit. p 16.

large representation in the Committee of Ten of the National Education Association, which reported in 1894. The Conference of Physics, Chemistry,and Astronomy of this Committee made twelve specific recommendations for Physics teaching in the high school. [3] This report stressed laboratory work, quantitative and mathematical treatment, and it recommended more widespread teaching of sciences throughout the school system. The general tone of the Committee of Ten was one of emphasis on subject-matter rather than on pupil personality, of belief in the fundamental importance of science, and of faith in mental discipline through scientific studies. This report was followed by the work of the Committee on College Entrance Requirements of the National Education Association. This Committee published recommendations for a high school Physics course, the "National Physics Course", based upon the entrance requirements of Harvard College, which was widely adopted.

Early science in the secondary school was based upon practical applications and everyday experience; it was built upon a firm apperceptive foundation. But as the grip of the university on the high school became more secure, Physics, together with many other subjects, became more abstract and difficult, further removed from the pupils' interests. Physics became a highly organized body of knowledge, held together by a logical mathematical structure, but devoid of appeal to the adolescent. "Learning for learning's sake" has been a fault of teachers in all ages, and the closing years of the nineteenth century saw this fault transmitted from the university to the high school,

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[3] Rowland, op.cit. p 41 et.seq.

so far as science was concerned.

The opening years of the twentieth century were marked by a new movement in the teaching of high school Physics, a reaction against the formalization and abstraction of the preceding twenty years. This movement was chiefly the result of voluntary action by the high school teachers, who sought to enliven their subject by connecting it with the phenomena of everyday life. It was a part of that broader movement of scientific expansion which was marked by the development of commercial electricity, the automobile, steam turbine, and many other accomplishments of engineering. Various organizations of science teachers have been concerned with improvement of teaching methods, vitalizing high school courses and adapting them to the needs of their pupils. The pupil, his needs and desires, has now become the center of attention, rather than the subject-matter of the course.

This movement is still active. The American public school is at least as conservative and inert as other social institutions, but a change is slowly being wrought in its methods, even in that very conservative field of the sciences. There is at present a growing demand for correlation among the subjects in high school science. Educators now realize that the primary purpose of the high school is not to inculcate facts, but to develop habits of right thinking and right acting, to furnish an introduction to the world's store of knowledge, to open eyes to the beauty and majesty, as well as to the evil and ugliness, of the world, to form the child into an able and useful social being, a citizen.

Science as a high school study is a powerful instrument

for accomplishing these purposes. In Chapter IV below, I shall discuss the present tendency to apply Physics to these purposes, as indicated by the declared objectives of Physics courses.

CHAPTER II.

ENROLLMENT IN HIGH SCHOOL PHYSICS.

The statement is frequently made in educational literature that Physics is declining in popularity as a high school curriculum subject.[1]

> "It may be that the final word on the organization of[2] a course in Physics has been said. On the other hand, the decline in the enrollment in the subject at least suggests that a reorganization with a change of emphasis might be desirable."

Figure 1, page 10, indicates the trend in enrollment in this subject in high schools of the United States from 1890 to 1928. These figures were tabulated by the United States Office of Education.[3] Since these tabulations are made only at five-year intervals and are delayed at least one year in publication, no figures are available since 1928. A new tabulation is due to appear within the next year or two. Figure 2, page 11, indicates the enrollment in Physics in relation to the total high school enrollment for the whole country.

It is seen from Figure 1 that the number of high school pupils enrolled in Physics courses has steadily increased since 1890, the enrollment in 1928 being about four times that in the former year. Beginning in 1910 there was a marked increase in the popularity of Physics. This was concomitant with the reform

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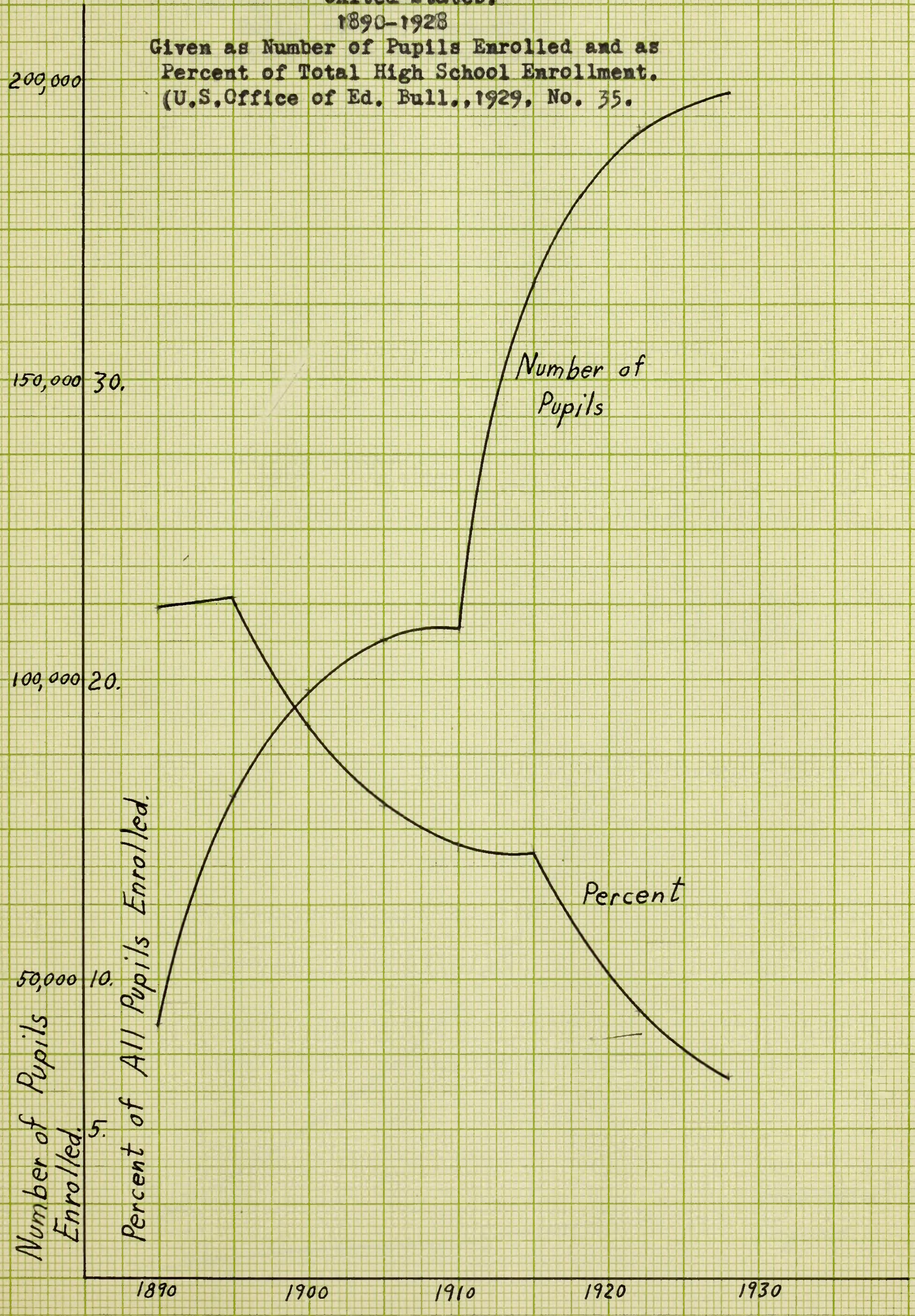
[1] H.W.LeSourd. To what extent shall secondary school physics be mathematical? Sch.Sci.and Math. 32:777-9, O '32.

[2] U.S.Office of Ed. Bull.,1932, No.17. Monograph No.22. Instruction in science. p 36.

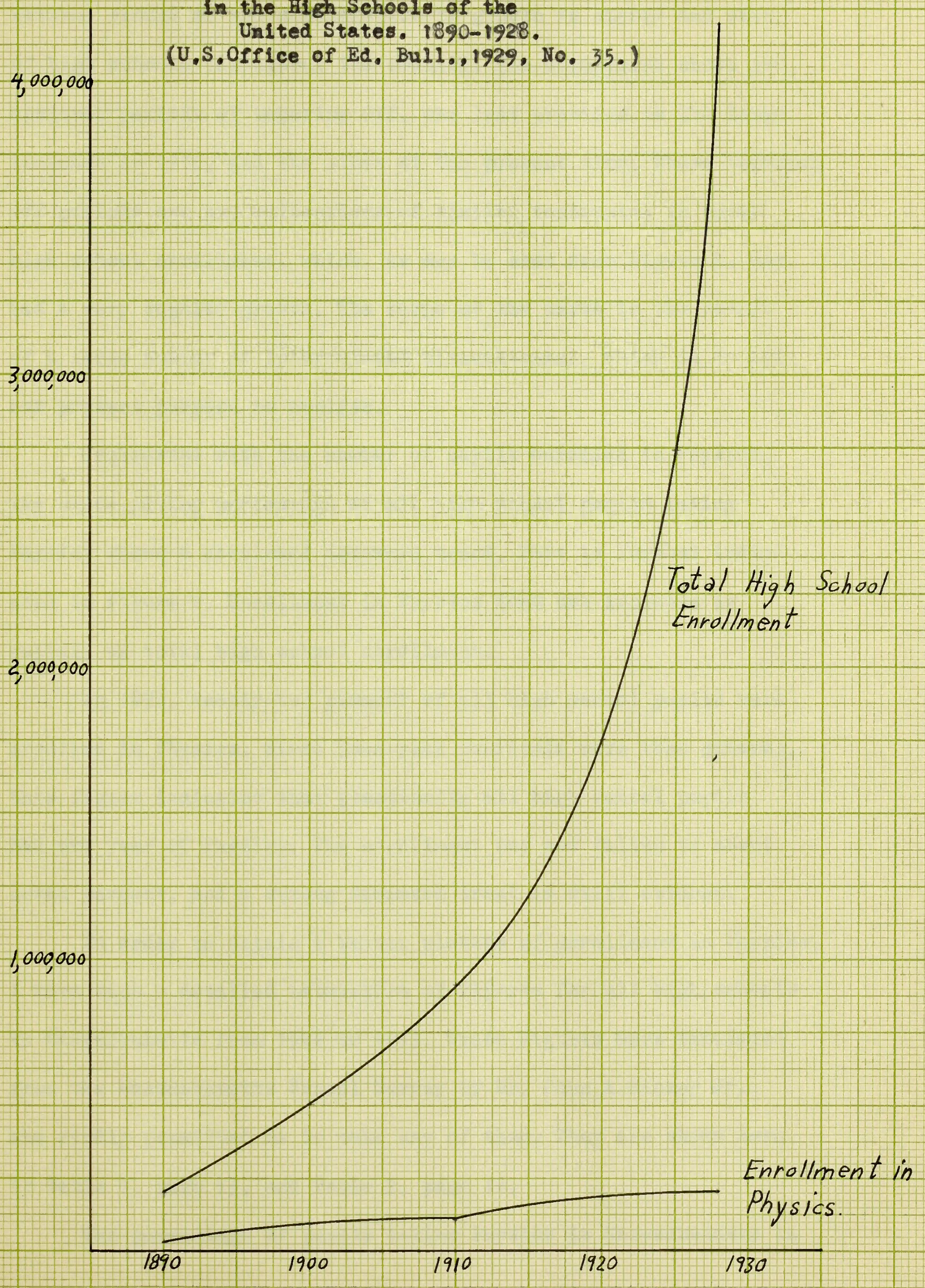
[3] U.S.Office of Ed. Bull., 1929, No.35. Biennial survey for 1927-28.

FIGURE 1.
Enrollment in Physics in High Schools of the United States.
1890-1928
Given as Number of Pupils Enrolled and as Percent of Total High School Enrollment.
(U.S.Office of Ed. Bull.,1929, No. 35.



KEUFFEL & ESSER CO., N. Y. NO. 358-11
20 × 20 to the inch.

FIGURE 2.
Total Enrollment and Enrollment in Physics in the High Schools of the United States. 1890-1928.
(U.S.Office of Ed. Bull.,1929, No. 35.)



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20 × 20 to the inch.

movement in science teaching during the early part of the present century, which sought to vitalize the subjects. It was also a natural result of the acceleration in growth in number and size of high schools throughout the country. The enrollment shows two distinct periods of tapering off, one just previous to the large increase in 1910, and the other at the present time. These tapering off periods are not reflections of similar tendencies in total high school enrollment, which, as may be seen from Figure 2, has had a very regular growth. The shape of the curve is the result of a large number of interrelated circumstances, which it is not our present purpose to analyze.

Contrasted with the number of pupils enrolled in Physics, the curve giving percentage of all high school pupils taking Physics shows a continual downward trend. This is further indicated in Figure 2. Enrollment in Physics does not increase as rapidly as total high school enrollment.

In 1890, twenty-two percent of all high school pupils were enrolled in Physics. Since four-year curricula were then general, this figure indicates that practically all high school pupils had one year of Physics. The enrollment has now fallen to about seven percent, and a strong downward trend is still evident.

In order to obtain a better picture of enrollment in Physics, I have made a detailed tabulation of figures for all high schools in Massachusetts from 1924 to 1933. These figures were tabulated from the Massachusetts School Survey by Mr. John.A.Ricker Jr., who kindly permitted me to make use of them. They are shown here in Table 1, page 13, and Table 2, page 14.

The percentage of pupils taking Physics in Massachusetts in

TABLE 1.

Physics Courses Taught and Enrollment in Massachusetts High Schools.
1924- 1933.
(Courtesy of Mr.John.A.Ricker Jr.)

		1924-25	1928-29	1932-33
Total Enrollment in all Physics Courses. . . .		9,078	9,254	12,260
Number of Schools Teaching Physics.		178	181	184
Percent of All Pupils in Mass.High Schools Taking Physics. .		7.76	7.53	7.82
Special Courses in Physics.				
General Physics.	Pupils Enrolled.	178	103	303
	Schools Teaching	2	2	4
Practical Physics.	Pupils Enrolled.	31	171	248
	Schools Teaching	1	2	2
Household Physics.	Pupils Enrolled.	26	-	289
	Schools Teaching.	1	-	2
Elementary Physics.	Pupils Enrolled.	186	105	-
	Schools Teaching	2	3	-
Everyday Physics.	Pupils Enrolled.	-	24	-
	Schools Teaching	-	1	-
Applied Physics.	Pupils Enrolled.	-	20	-
	Schools Teaching	-	1	-
Industrial Physics.	Pupils Enrolled.	-	-	46
	Schools Teaching	-	-	1
College Physics. (Preparatory)	Pupils Enrolled.	-	-	231
	Schools Teaching	-	-	7
Enrollment in All Special Courses.	Number.	421	423	1,117
	Percent of Total Physics Enrollment	4.64	4.56	9.10
	Percent of Total School Enrollment	0.36	0.34	0.71

TABLE 2.

Physics Teaching in Massachusetts High Schools, According to Size of Schools. 1932-33.
(From Mass. Dep't of Ed. School Survey.)

	Group 5	 4	 3	 2	 1
Total Number of Pupils Enrolled .	416	2,641	8,129	17,459	129,711
Pupils Enrolled in All Physics Courses. Number	29	217	345	989	10,680
Percent of Total Enrollment	7.0	8.2	4.2	5.7	8.2
Total Number of Schools in Group	10	37	49	56	97
Number of Schools Offering Physics and Chemistry Alternate Years	3	10	16	9	-
Number of Schools Not Offering Physics	3	6	12	5	1

Note: All the Special Course in Physics listed in Table 1 are given in schools in Group 1, except for one school in Group 2 which offers General Physics, with a enrollment of 20.

1928 is slightly higher than that in the nation as a whole, 7.53 as against 6.85. No definite trend in enrollment is evident during the nine-year period covered by this tabulation.

The special courses in Physics are of considerable interest. The survey revealed eight differentiated subjects, dealing chiefly with practical, everyday aspects of physical science. Of these subjects, General, Practical, and Household Physics appear to be increasing in popularity. Elementary Physics is disappearing, probably being displaced by General or Elementary Science. Only a few schools offer differentiated courses in Physics, and these, with one exception, are among the largest schools in the state.

Table 2 gives data on Physics courses for schools of different size. The grouping of schools is that used by the Massachusetts Department of Education.

Enrollment.	Group.
0-50 pupils	5
50-100 "	4
100-250 "	3
250-500 "	2
over 500 "	1

Group 1 includes eighty-three percent of all high school pupils in Massachusetts, and consequently shows by far the largest number registered in Physics. The figures of percentage of all pupils in each group enrolled in Physics are more significant than the actual number of pupils. Physics appears to be least popular in Groups 2 and 3, including schools having enrollments of from 100 to 500.

A considerable number of Massachusetts high schools employ the device of offering Physics and Chemistry in alternate years.

About one-third of the smaller schools report the use of this scheme. About one-sixth of the schools in Group 2 also use it.

About one-fourth of all schools enrolling 250 pupils or less do not offer Physics, or at least had no pupils taking it in 1932-33. The one school in Group 1 which has no enrollment in Physics is a large Girls' Latin School.

The following conclusions may be drawn from the data presented above:

1. For the next few years, it is probable that enrollment in Physics courses will increase at a slower rate than total high school enrollment.

2. There is substantially less demand for instruction in Physics in schools of less than 500 enrollment than there is in the larger schools.

3. There is a growing tendency to differentiate Physics into separate fields of application, mostly of a practical nature. An interesting commentary on this tendency is the action of several Massachusetts high schools in offering both "College" and "Practical" Physics. Evidently the Physics required for entrance into college is not "Practical".

CHAPTER III.

TRAINING, EXPERIENCE, AND OTHER DUTIES OF HIGH SCHOOL SCIENCE TEACHERS.

It is a difficult matter to obtain data on education, experience, and other duties of Physics teachers from a sampling large and wide enough to be truly representative. Time limitations in this study precluded the use of a questionaire. Moreover, such a questionaire would be unsatisfactory unless sent out by an authoritative power, because of the low returns commonly received, (25 to 50 percent) and because of some selectivity in the results.

The Massachusetts Department of Education School Survey for 1932-33 includes data on degrees held, experience, salary, sex, and teaching and administrative duties of all high school teachers in the state, and I made use of this information in tabulating the results here given. Unfortunately, teachers are listed simply as teachers of science, without specifying the particular subjects which they teach. I have therefor included all science teachers in this study, although some of them certainly do not teach Physics. Results are tabulated for each group of schools, as classified by the Department of Education. This classification is described above on page 15.

Table 3, page 18, indicates the college degrees and normal school training of all science teachers. In making this tabulation I noted only the highest degrees held, except when lower degrees had been received in Education. All degrees in Education are included, together with any other degrees which that teacher may hold. The columns therefor do not total properly, as noted on page 18, since more than one degree may be specified for one teacher.

TABLE 3.

Degrees Held by Science Teachers in Massachusetts High Schools. 1932-33.

Degree.	Number of Teachers. Group 5	4	3	2	1
Bachelor of					
Arts	4	17	25	43	235
Laws	-	1	1	1	7
Philosophy . . .	-	1	2	1	20
Science	8	21	32	45	182
" in Education	1	2	2	3	8
" " Engineering	-	1	1	4	5
Master of					
Arts	-	7	2	7	61
Education . . .	-	2	2	6	43
Science	-	1	-	2	17
Doctor of Philosophy	-	-	-	-	1
Normal School(at least 2 yrs)	-	5	2	-	20
No Degree	-	7	2	1	28
Total number of teachers.	13	54	70	100	506

	Percent of Teachers in each Group. 5	4	3	2	1
Bachelor of					
Arts	31	31	36	43	46.5
Laws	-	2	1.5	1	1.4
Philosophy . .	-	2	3	1	4
Science . . .	62	39	46	45	36
" in Education	7	4	3	3	1.6
" " Engineering	-	2	1.5	4	1
Master of					
Arts	-	13	3	7	12.1
Education	-	4	3	6	8.5
Science	-	2	-	2	3.4
Doctor of Philosophy	-	-	-	-	0.2
Normal School . . .	-	9	3	-	4
No Degree	-	13	3	1	5.5

Note: Each column does not add up to the total number of teachers or to 100 percent, since degrees in Education have been included with other degrees held by the same teacher.

Baccalaureate degrees naturally preponderate, and are roughly evenly divided between Arts and Science. The Science degree tends to be more common in small schools. Group 5 includes only thirteen teachers, and is probably not a good representation of such small schools in general. Bachelor degrees in Education are not popular, being held by about five percent of all these teachers. Engineering degrees are held by about two percent of these teachers.

Master of Arts degrees are fairly common in all groups. Master of Education degrees are found most frequently in the larger schools, where there is usually greater incentive and more insistence for the teachers to extend their formal education. I consider it rather remarkable that so few Master of Science degrees appear, even in the larger schools.

An appreciable proportion of science teachers possess no degree, according to this survey. Some of these are older teachers who have had Normal School training, and some of them, according to the returns of the survey, have spent four years in college without obtaining a degree. Some of these returns are possibly due to error or oversight in making out the forms, but it causes some suspicion of undesirable or incompetent persons in teaching positions.

Table 3 gives no evidence of a high level of academic achievement among Massachusetts high school science teachers. It indicates the fact that there is no uniform set of requirements for high school teachers in this state. However, academic achievement alone does not make a teacher competent or successful, nor does absence of it prove the reverse qualities. There is indication of lack of emphasis upon scientific education. There is also

evidence of entirely insufficient emphasis upon training in educational theory and method. Subject-matter is considered to be the important requirement for high school teachers. This is a common fault of the American high school, according to Draper and Roberts.[1]

Table 4, page 21, indicates the sex of high school science teachers in Massachusetts. About two-thirds of all science teachers are men. There is no evidence of any tendency for the proportion of men to women teachers to depend on the size of school, although Group 3 has only about one-half as great a percentage of women. Group 5 includes no women science teachers. Since only ten schools are included in this group, the results may not be indicative of general practice in the smallest schools. However, in these small schools the science teaching is usually done by the principal, who is usually a man. The principal is frequently the only man on the faculty, and he is more apt to possess the necessary education to teach science subjects.

Table 5, page 21, indicates the amount of teaching experience of high school science teachers in Massachusetts. There is evidence of a distinct tendency for larger schools to employ older teachers of science subjects. Group 5 has no teachers of more than ten years experience, while one-fourth of the teachers in Group 1 have taught for more than twenty years. The intermediate groups, including schools with from 50 to 500 pupils, all show about the same distribution; about one-half beginning teachers, about one-fourth with six to ten years experience, and about one-tenth with over twenty years. The length of service of these older teachers

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[1] Principles of American secondary education. 1932.

TABLE 4.

Sex of Science Teachers in Massachusetts High Schools. 1932-33.

	Number of Teachers.				
	Group				
	5	4	3	2	1
Men	13	38	58	74	338
Women	-	16	12	26	168
Total Number of Teachers	13	54	70	100	506
	Percentage of Teachers.				
Men	100	70	83	74	67
Women	-	30	17	26	33

TABLE 5.

Years of Teaching Experience of Science Teachers in Massachusetts High Schools. 1932-33.

	Percent of Teachers in each Group				
	Group				
Experience	5	4	3	2	1
0-5 years.	55	45	52	54	19
6-10 "	45	26	26	21	25
11-15 "	-	16	8	11	19
16-20 "	-	3	6	6	13
over 20 "	-	10	8	8	24
Total Number of Teachers considered here	9	38	65	97	489

Note: Data are not available for all teachers regarding their experience.

runs as high as forty-five years in a number of cases.

I have not tabulated figures to indicate how long teachers remain in the same school, but my impression from examining the survey is that they tend to remain permanently located, particularly in the cases of the older teachers and the larger schools.

Table 6, page 23, indicates administrative duties and subjects taught, other than science, by these teachers. It is noted that the percentage of teachers who devote their entire attention to science subjects increases regularly with the size of school, from none in Group 5 to eighty-five percent in Group 1.

In the smaller schools, science subjects are commonly taught by the principal. The frequency of this combination of duties decreases as the size of school increases.

A considerable number of science teachers also teach mathematics, except in the largest schools. This is the most frequently found combination of subjects in this table.

A large number of other combinations is found, but none of them shows a high frequency. Certain obvious combinations, as; Science and Industrial Arts, Science and Household Arts, Mathematics and science and Industrial Arts, are found. The Household Arts teachers probably do not teach Physics. Aside from this probability there is no way of determining which of the science teachers have Physics classes.

The number of science teachers per school is surprising.

TABLE 7.

Number of Science Teachers per School

Group.

1	2	3	4	5
1.3	1.46	1.43	1.79	5.22

TABLE 6.

Other Duties of Science Teachers in Massachusetts High Schools. 1932-33.

	Number of Teachers in each Group				
	5	4	3	2	1
Teach Science only. . .	-	3	11	49	412
Other Subjects and Duties in addition to Science Teaching.					
Mathematics,Principal. .	4	12	14	-	1
Mathematics	1	12	17	21	31
History,Principal . . .	3	3	8	9	-
Principal	-	2	2	7	-
History,Mathematics,Principal	2	3	-	-	-
Ancient Languages	-	4	1	2	2
Household Arts . . .	-	3	1	3	2
English	-	2	3	4	11
Coaching, Physical Education	-	-	-	4	10
Commercial	-	-	4	1	4
Mathematics,Industrial Arts	-	2	1	2	-
History,Modern Languages	-	1	1	-	1
English,History . . .	-	-	2	1	-
History,Commercial . .	-	-	2	1	-
Mathematics,Commercial	-	1	-	-	1
Mathematics, Commerc.Principal	1	1	1	-	-
Mathematics,History	1	1	-	-	-
History,Math.Ancient Lang.	-	-	-	1	-
Hist.Math.Anc.Lang.Principal	-	1	-	-	-
History,Ancient Languages	-	1	-	1	-
History,Household Arts	-	-	1	-	-
English,Household Arts	-	-	1	-	-
History	-	-	-	-	11
Modern Lang. Principal .	1	-	-	-	-
Industrial Arts . . .	-	-	-	1	-
Total Number of Teachers	13	52	70	107	486
Percent who teach Science only	-	6.	16.	46.	85.
Percent who are Principals	77.	38.	33.	15.	0.2
Percent who also teach Math.	69.	63.5	47.	23.	6.8

The largest schools have a much greater number than the smaller ones. A number of small schools report two or three of their teachers giving science subjects. This occurs probably because of lack of preparation on the part of the teacher to teach all science subjects offered.

CHAPTER IV.

OBJECTIVES OF HIGH SCHOOL PHYSICS COURSES.

W.L.Beauchamp[1] has tabulated the expressed objectives of twenty-seven high school courses which have been reorganized since 1925, in connection with the National Survey of Secondary Education. The returns from this survey on science instruction are rather meager, when the total number of high schools in the United States is considered.

> "Assuming that a least the majority of school administrators were sufficiently interested in the survey to send courses of study if they were available," - when the generally high percentage of returns from this survey is considered - "the results probably indicate that a very large majority of schools do not have recently revised courses of study for science instruction at the secondary level".[2]

This analysis

> " . . . . should be indicative of the progress which is being made. Because of the small number of courses analyzed, it cannot be construed to be a picture of general practice; it presents practice in school systems where recent revisions have been made and where the situation in science instruction is probably more dynamic than in the general run of secondary schools."[3]

Table 8 indicates the type of objectives reported.

TABLE 8.

Number of Courses analyzed.	27
" reporting objectives of secondary education	-
" " " of science in general	2
" " " " specific courses	18
" referring to other committees	1
" not reporting objectives	6

Table 9, page 26, indicates the number of Physics courses which listed each objective.

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[1] U.S.Office of Ed.Bull.,1932,No.17. Monograph No.22.

[2] Ibid, p 1.

[3] Ibid, pp 1, 2.

TABLE 9.[4]

Objectives of Physics courses.	Number of courses listing each.
A. Knowledge.	
To acquire knowledge which will produce a better understanding of our environment	14
To acquire a knowledge of the fundamental principles of Physics.	10
To acquire knowledge which will help to secure Citizenship	9
To secure knowledge which will help to secure Health	7
To acquire the knowledge necessary for future courses in science or in college	6
To gain worthy home membership	5
To aid in one's vocation	5
To correct superstition and erroneous beliefs	2
To increase one's general culture	1
To gain command of fundamental processes	1
To meet demands of state courses of study	1
B. Exploration or Orientation.	
To give the pupil a general view of the field of science	5
to acquire new fields of interest	4
as a basis for election of further science courses	3
as a basis for selecting a vocation	2
C. Abilities.	
To develop ability to think scientifically	9
To develop the power of observation	9
To develop ability to gather data systematically	4
To develop ability to do quantitative thinking	4
To develop ability to use scientific instruments	4
To develop the power of interpretation	2
To develop the ability to evaluate	2
To develop ability to express ideas in clear and coherent English	2
D. Attitudes.	
Appreciation of contribution of science to mankind	6
To be open-minded	5
To suspend judgment until all the facts are secured	2
To be free from dogma and superstition	1
To revise opinion if evidence warrants	1
To appreciate great men of science	1
Appreciation of nature	1
Importance of quantitative thinking	1
Importance of original research	1

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[4] U.S.Office of Ed.Bull.,1932,No.17.Monograph No.22. pp 11,12.

TABLE 9. (continued)

Objectives of Physics courses.	Number of courses listing each
E. Ideals and Habits.	
To acquire ideals or habits of accuracy, persistence, honesty, self-control, truth, etc.	6
F. Interests.	
To acquire wholesome interests which may be used to enjoy spare time	7
To acquire an interest in taking more science	2
To acquire an appetite for scientific reading	1

At present there seems to be no method of evaluating these objectives. Table 9 merely represents the consensus of opinion. As Beauchamp says [5], these objectives

> "are significant in that they indicate what objectives are entertained but they are not necessarily the objectives which should be attained in the study of science. For example, of the 160 courses examined" - in all science subjects - "only 11 courses stated the objective 'To acquire knowledge necessary to correct superstition and erroneous beliefs.' According to the consensus of opinion this is only a minor objective in the teaching of science. The writer is of the opinion that this is an important objective. This is an opinion only and we have no present means of validating it."

There is, then, no standard available at present to which we may compare objectives of high school Physics. The evaluation of these objectives is a matter of authoritative opinion.

The National Society for the Study of Education has published a discussion of the objectives of science teaching, which Beauchamp recommends as probably the best composite thinking which has been done on this question.[6] The Committee on Science Teaching of this Society makes a practical approach to the problem of science objectives:

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[5] U.S.Office of Ed. Monograph No.22. op.cit. p 13.

[6] 31st Yearbook of the Society. Part I. A program for teaching science. Public School Pub.Co. 1932.

> "This Committee, then, recognizes the aim of science teaching[7] to be contributory to the aim of education; viz., life enrichment. It recognizes the objectives of science teaching to be the functional understandings of the major generalizations of science and the development of associated scientific attitudes."

The aim of education is defined as

> "Life Enrichment through Participation in a Democratic Social[8] Order."

> "The principles and generalizations that ramify most widely[9] into human affairs may be stated as the objectives of science education. The objective may be seen then as differing from the aim of education chiefly in its scope. . . . The objectives may be stated as the principles and generalizations that are functional for the individual, in that they enable him to interpret the experiences of living. The objectives may be formulated (1) as statements that function directly in thinking, (2) as statements that describe methods of thinking, and (3) as statements that describe attitudes toward products of thought and toward methods of thinking. These three types of objectives, although distinguishable, cannot be regarded as mutually exclusive. From the point of view of their origins in the educative process, these objectives are closely similar."

This approach to the problem of objectives in science teaching makes possible a very definite statement of specific, practical objectives. The Committee's report offers a list of thirty-eight definite objectives, from which I quote eighteen which apply directly to high school Physics courses. As a matter of fact, this Committee has in mind, not specific courses in the different fields of science, but a unified and continuous program of science education throughout the school system.

The selected objectives are:

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[7] 31st Yearbook, op.cit. p 57.

[8] Ibid, p 42.

[9] Ibid, p 43.

Principles and Generalizations Suggested by the Committee as Valuable for Guidance in the Selection of Specific Objectives of Science Teaching.[10]

1. The sun is the chief source of energy for the earth.

- - - -

5. Matter and energy cannot be created or destroyed, but may be changed from one form to another.

- - - -

10. Units of time are defined by the earth's movements in relation to the sun.

- - - -

18. Chemical and physical changes are manifestations of energy changes.

- - - -

21. Certain material substances and certain physical conditions are limiting factors to life.
22. Light is a limiting factor to life.
23. Sound is caused by waves which are produced by a vibrating body and which can affect the auditory nerves of the ear.
24. Gravitation is the attractive force that influences and governs the movements of astronomical bodies.
25. Machines are devices for accomplishing useful transformations of energy.
26. Any machine, no matter how complicated, may be analyzed into a few simple types.

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28. All matter is electrical in structure.
29. The applications of electricity and magnetism in the home and in industry have revolutionized the methods of living of many people.

- - - -

31. The kinetic energy of molecules determines the physical states of matter.
32. The gravitational attraction between the earth and a mass of unconfined gas or liquid causes the pressure of the gas or liquid on the surface of the earth.
33. Liquid or gas pressure is exerted equally in all directions.

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35. A change in rate or direction of motion of an object requires the application of external force.
36. Radiant energy travels in straight lines through a uniform medium.
37. Electricity is a form of energy that results from disturbing the position or the regular paths of electrons.

This list indicates the type of objectives recommended by this Committee. They are general principles which are involved in everyday life situations.

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[10] 31st Yearbook, op.cit. pp 53 tp 55.

A.W.Augur [11] has given a very cogent discussion of objectives in Physics, agreeing in principle with the trend of thought of the National Society's Committee. He states the great objective of all education to be the transmittal of our racial heritage of knowledge and institutions. This objective is very broad:

> ". . . . it is distressingly useless when we attempt to plan [12] a specific course in a definite and limited field such as Physics."

He then proceeds to an analysis of the purposes of school courses. [13]

> "The Immediate Objectives of any Special Course are
> (a) To supply tools for future work.
> (b) To impart specific information.
> (c) To develop valuable skills and habits.
> (d) And above all, to set the feet on the roads which shall lead to the treasure house of the world.
> Many other important objectives, such as Good Citizenship, Health, Right Employment of Leisure, are worthy of thought but can have almost no value in planning a course in Physics."

This last statement is interesting in view of the analysis by Clemensen which is discussed below, on page 32.

Augur goes on to prescribe the [13]

> "Primary Objectives of Physics.
> (a) To develop initiative and skill in stating, attacking, and solving concrete problems and difficulties.
> (b) To cultivate the scientific attitude of mind.
> (c) To emphasize the place of the natural sciences in the present day world and especially to cultivate a taste for Physics.
> (d) To impart useful information."

He also states the requirements of laboratory experiments in Physics: [13]

> "(a) Must contain a real and felt problem, question, or difficulty.
> (b) It must provide a way of solving the problem.
> (c) The conclusions reached must be of value to the student

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[11] Plan for securing individual work in Physics. Ill.U. high school visitor's office.Proc.of H.S.Conf. 1930.

[12] Ibid, p 267.

[13] Ibid, p 268.

(d) The pupil must to some extent make his own plans for attacking the problem, and the more the better."

F.J.Mulder indicates the samr trend of thought in a discussion of subject-matter of Physics courses. He believes that subject-matter must be considered carefully, and that the objectives must be interpreted in terms of it. He lists the following purposes of subject-matter; [14]

"1. Assists in teaching scientific attitude and method.
2. " " building up appreciation of scientific achievements.
3. Reveals the general cause and effect relationship in nature, and overcomes superstition.
4. Directly prepares for further work in science or vocation.
5. Reveals nature, requirements, possibilities, of scientific and engineering vocations, thus assisting in guidance.
6. Enables one to read scientific articles in newspapers and magazines intelligently.
7. Satisfies natural interest in nature.
8. Helps directly in using many appliances and principles of physical science common in everyday life.
9. Gives insight into the organization of the world, enables one to see it as a whole instead of a lot of disjointed parts."

These items are objectives which are of immediate value in selecting the subject-matter to be included in a course in Physics.

Victor H. Noll, who assisted the Committee of the National Society referred to above, also stresses the practical importance of subject-matter in discussing one particular objective, that of developing the habit of scientific thinking. He maintains that the only proper way to attain anobjective is to aim directly at it. "Learn to do by doing", and do not rely on transfer of training to attain ends in one subject by studying another.

"The natural sciences present some of the best though not [15]

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[14] Some questions concerning the place of subject-matter in the teaching of physics. Sch.Sci.and Math. 32:272-81,Mr '32.p274.

[15] T.C.Record. 35:202-12, D '33. p203.

the only materials for use in forming habits of scientific thinking."

"The habits of thinking that . . . . constitute the scientific attitude should be taught and developed directly as such."[16]

"Practice must be given in the formation of these habits in specific situations."[17]

Jessie W. Clemensen has given a very detailed outline of objectives for high school Physics in the development of a complete set of study outlines.[18] Miss Clemensen made no attempt to reorganize the subject-matter of Physics; she followed the traditional organization of the subject. Her contribution consists in definitely formulating practical objectives, in arranging subject-matter and developing methods of instruction which would realize these objectives. Her scheme of objectives is extremely interesting since it is founded upon the Seven Cardinal Principles of Secondary Education, and I shall quote it here in some detail.

OBJECTIVES OF HIGH SCHOOL PHYSICS.[19]

General Objectives.

1. Developing physical fitness through an understanding of the physical laws governing certain conditions necessary to health.
2. Applying fundamental processes in physical science to scientific and social phenomena.
3. Discovering interests and aptitudes through a knowledge of the type of work and training required of those engaged in occupations based upon physical science, such as engineering, aeronautics, surveying, astronomy, telephony, etc.

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[16] T.C.Record. 35:205.

[17] T.C.Record. 35:206.

[18] Teachers College, Columbia University. Contribution to Education No. 553. 1933.

[19] Ibid, Appendix A, p 113 et.seq.

4. Using native capacities to the maximum in the field of scientific thought and activity.
5. Preparing for economic independence or advanced training.
6. Providing opportunities, and developing capacities for participation in diversified aesthetic and recreational activities based on physical science.
7. Evolving high standards of conduct in personal and group life through the interpretation and appreciation of the laws and methods of physics.
8. Contributing to worthy home life through application of the laws of physics to the home.
9. Developing an appreciation of the contribution of physics to our present-day life.
10. Developing an understanding of the significance of physics in the interrelatedness of world groups.

There follow Specific Objectives for each division of the field of Physics, Mechanics, Heat, Magnetism and Electricity, Sound, Light and Invisible Radiations, based upon the General Objectives given above. I shall give here only a few examples of her scheme, which indicate the way in which each subject may be applied to the fulfillment of the General Objectives.

Specific Objectives - Mechanics.[20]

1. Developing physical fitness . . . .
    a. Understanding of the conditions for bodily stability . . with appreciation of these as the underlying laws of correct posture . . . .
    b. Understanding and appreciation of the marvelous lever construction of the human body , . . .
2. Applying fundamental principles in physical science to scientific and social phenomena.
    a. Workable knowledge of only the most common English and metric units of measurement . . . .
    b. Usable knowledge of the meaning of, and conditions affecting efficiency, as applied to simple machines.
    c. Understanding and appreciation of the manner in which one principle of natural phenomena (especially Law of Work for Machines) may be mathematically stated and used in many specific cases.
    d. Ability to use common measuring instruments - . . . .
    e. Information concerning percentage of error in measurements, degree of accuracy required for various types of work, . . . together with a high degree of accuracy in collecting and reporting data.

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[20] Contrib.to Ed. No.553. pp 116, 117.

> f. Information concerning, and appreciation of the methods used by architects and engineers in plannihg details of a structure . . . ; idealization of this method of scientific procedure of planning, as most efficient in all fields and a saver of time, energy, and materials.

3. . . . . . .

Miss Clemensen carries out such a detailed scheme for the whole field of Physics. This scheme formed the basis for study outlines, which were used in a large-scale experiment in the high schools of Los Angeles, with very gratifying success both with regard to learning achievement and pupils' interest.

Muthersbaugh [21] in 1929 made a careful study of objectives expressed in textbooks and courses of study, in order to formulate objectives for a new course of study in the high schools of Cleveland, Ohio. The course was organized into twenty units, such as; Water; Air; Aviation; Electricity in the Home; Principles of Magnetism; etc. Objectives were established for each unit, chosen from a list of 221 objectives resulting from the study. These objectives are specific. Appreciations are neglected. There is no evidence of their being based upon the Seven Cardinal Principles. Knowledge is stressed; nearly every statement begins with the words "to know" or"tounderstand". I quote the statements of two units here to indicate the general trend of the formulation.

"Objectives of a Proposed Course in Physics for Senior High Schools. [22]

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Unit 3. Water.

12. To know what pressure in a liquid is and how it is measured.
13. To know what the total force of a liquid is and how it is measured.

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[21] Objectives of a proposed course of study in physics for senior high schools. Sch.Sci.and Math. 29:943-54, D '29.

[22] Ibid, pp 946,947.

Unit 8. Machines: Industry.

31. To know what work is and how it is measured.
32. To know how machines aid us in doing work.
33. To know how to apply energy most effectively to the different types of machines in everyday use.
34. To know how to apply energy most effectively to the lever to lift or move a heavy body.

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While none of these objectives mention appreciation directly, many of them give a clever teacher ample opportunity for developing it. It appears to me that the entire formulation of objectives here leaves the individual teacher too much liberty of interpretation. It is hopeless to expect a high school Physics class to attain mastery of all the 221 specific knowledge outcomes stated in the outline.

From the foregoing digest of present-day opinion in regard to the objectives of high school Physics, the following tendencies may be noted:

1. There is a strong tendency to use the Seven Cardinal Principles of Secondary Education as a framework on which to build a system of objectives.
2. Great emphasis is placed upon understanding and ability to use the relatively few fundamental principles and major generalizations of Physics.
3. Great emphasis is placed upon the development of appreciations.
4. There is a strong tendency to bring Physics home to the pupil, by drawing materials from his everyday experiences and environment, and by stressing the importance of Physics in his own life.
5. Little importance is attached to the inculcation of a large amount of factual information.

6. The actual practice, even in high schools selected because of their recent reorganization, is far short of that specified by the best opinion in regard to objectives.

CHAPTER V.

PROVISION FOR INDIVIDUAL DIFFERENCES.

Little data appear to be available on the range of individual differences actually encountered in high school Physics classes. Students of Physics probably form a somewhat more selected group than the high school enrollment as a whole, since it is a subject taken largely by those who intend to enter college, it is always offered in either the junior or senior year, and admission to it tends to be conditional upon ability in prerequisite subjects which usually require a high degree of abstract intelligence.

Hurd[1] reports, from a study of a group of eighty-three Physics pupils, a range of I.Q.'s of from 80 to 129, with a median of 109, an age range of from fourteen to nineteen years, a range of scores in a prognostic test of from 0 to 29, and a sex proportion of 59 boys to 24 girls. Clemensen[2] reports an average I.Q. of 114 for a large number of Physics students in Los Angeles high schools, but does not state the extreme ranges. Carter[3] reports results from a group of 404 pupils, 274 boys and 130 girls. His range of I.Q.'s is from 70 to 130, with a median at 106, and inter-quartiles at 96 and 114. These figures indicate considerable selection, since the distribution curve is sharply peaked.

Physics appears to be preponderantly a boys' subject, the

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[1] Present inadequacies and suggested remedies in the teaching of physics. Sch.Sci.and Math. 30:539-45, My '30.

[2] Contrib.to Ed. No.553. op.cit.

[3] Math.Teach. 25:313-31, O '32.

proportion of boys to girls being about two to one according to the Committee of the National Society for the Study of Education.[3A] These figures are borne out by those given above.

The best authority on present practice in regard to individual differences is R.O.Billett's monograph. [4] This study indicates two methods applied specifically to Physics teaching; homogeneous grouping; and various plans using the unit assignment. Other methods discussed which may affect students of Physics are; continuous promotion or promotion by subject; scientific study of problem cases; advisory or guidance programs.

289 schools were selected as representing the best practice in the United States with respect to homogeneous grouping. This selected group represents all parts of the country and all sizes of schools. Thirty-two percent of these schools use homogeneous grouping in Physics, either within class sections, by differentiation of courses, or by grouping in separate class sections. [5] By the use of one or more of these schemes schools of all sizes may group pupils homogeneously.

Some examples will be shown to illustrate how grouping is actually carried out. The scheme of differentiated courses is illustrated by the special courses in Physics listed for Massachusetts in Chapter II above, page 13, affecting at present nine percent of all Physics students in that state.

[3A] 31st Yearbook, op.cit. pp 243,244.

[4] U.S.Office of Ed.Bull.,1932,No.17. Monograph No.13. Provision for individual differences, marking, and promotion.

[5] Ibid, p 68.

A form of homogeneous grouping within a class section is described by Harveson [6]. This scheme also has guidance features. It is used in Frankford High School, Philadelphia. Pupils beginning the study of Physics fill out a questionaire asking their preparation in science and mathematics, their interests and plans for future education, vocation, etc. They are also given the Iowa Aptitude Test in Physics. The teacher then advises each pupil, on the basis of this information, whether to take the regular or the non-mathematical course in Physics. The teacher merely advises; the pupil may elect whichever course he pleases. The two courses are parts of the same class section, and have the same laboratory work. The non-mathematical course eliminates practically all problem work, and substitutes study of biographical, historical, or current development topics. Each pupil presents reports of his studies to the class. Both groups have one supervised study period each week, when the teacher is available for consultation and assistance. Mathematical work is eliminated from the laboratory experiments as far as possible.

The scheme of grouping in separate class sections is illustrated by a plan used in the Central High School of Trenton, N.J. [7] The courses are organized on two levels; S_1 is college preparatory, the standards of which are those required by the colleges; S_2 is not designed to meet outside standards, but aims

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[6] Mae E. Harveson. Pupil grouping in physics to approximate individualization. Sch.Sci.and Math. 33:741-5, O '33.

[7] Information furnished me by courtesy of Dr.W.A.Wetzel, Principal.

to educate students to the limit of their capacity in scientific knowledge and thinking. Students are classified into these levels on the basis of reading ability index, previous marks, and the recommendation of advisers and teachers. During the course of the year, students are transferred according to their success. An S_1 student who fails is placed in S_2 level, and an S_2 student doing honor work is advanced to S_1 level. Standards of work in S_1 level are fixed. Grades in S_2 level are given on the basis of a normal distribution curve when a sufficiently large number of students is enrolled, 300 being considered sufficient.

Dr. Billett selected 362 high schools as representing the best practice in the use of various forms of the unit assignment, Morrison, Dalton, or Winnetka plan, or some modification of these. Eighty-one percent of these schools use some form of unit assignment in Physics classes.[8] Many different names are in use for the pupil's assignment, unit, job, contract, topic, block, enterprise, cycle, element, etc. The essential feature of all these plans is that the course is divided into a number of units, usually fifteen or twenty. Each pupil undertakes one unit at a time, and can proceed at his own rate and to an extent dictated by his own interests and abilities. Continuous promotion is a logical feature of these plans, and is frequently found in use.

R.C.Hollis[9] describes a method of this type in use in Waltham, Mass. Individual assignment sheets are issued, and the

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[8] U.S.Office of Ed. Monograph No.13. op.cit. p 332.

[9] Physics by an individualized method. Sch.Sci.and Math. 32:324-7, Mr '32.

amount of work required of each pupil is varied to suit his individual ability. Work of a mathematical or quantitative nature is required only for the highest grade. The class is kept together, so that all pupils work on the same unit simultaneously. Each unit is introduced by a lecture-demonstration, and a test is given when the unit is finished. There are no recitation periods; instruction is given by supervised study and individual pupil-teacher conferences.

V.C.Lohr [10] describes a "recitation" designed to take into account individual differences. Individual pupils present to the class talks, papers, or demonstrations on topics in which they are interested. This scheme has valuable concomitant results in developing ability to organize, present, and explain ideas, answer questions, "think on one's feet".

Programs of educational guidance affect the subject of Physics as they do other curriculum subjects, i.e., in determining whether an individual pupil should take the subject. Guidance is based upon a study of the individual through exploratory courses, measurement of interests, aptitudes, and learning ability, interviews, and any other devices which may be a part of the program. The scheme described by Harveson above, page 39, has guidance elements, but to be really effective the guidance of a pupil in Physics should be based upon a much more thorough study than is outlined there. No data are available, so far as I can determine, to indicate the extent, methods, or effectiveness of educational guidance in Physics.

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[10] Recitation: a product of mastery units. Ill.U. high school visitor's office. Proc.H.S.Conf. 1930. pp 272-5.

Dr. Billett's survey indicates that no use is made of out-of-school projects of studies in Physics.[11] It would seem, however, that such devices might be made of considerable value. Pupils are frequently found to have interests in applied physical science which they pursue as hobbies, and the school might well apply these interests to further the academic studies.

The rarity of such articles as I have reviewed in this chapter in the literature of science teaching indicates an apparent neglect of plans for providing for individual differences in Physics. The old method still largely persists of prescribing a definite amount of subject-matter for all pupils, and considering as satisfactory accomplishment an indicated proficiency of 60, 70, or 80 percent judged by the results of subjectively graded examinations.

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[11] U.S.Office of Ed. Monograph No.13. op.cit. p 399.

CHAPTER VI.

LABORATORY INSTRUCTION.

When Physics is specified as a college entrance requirement, the colleges in general require the performance of a specific list of laboratory experiments. A fairly uniform laboratory program has therefor come to be an integral part of most high school courses in Physics, based essentially upon the list of experiments given in the Harvard Descriptive List and the National Physics Course.[1] The great increase in enrollment in Physics in 1910 considerably overtaxed the laboratory facilities in many schools. Many of these students did not intend to offer the subject as a college entrance requirement, and the necessity of laboratory work was therefor decreased. This same situation arose also in Biology and Chemistry.

The overcrowding of laboratories led to a great deal of discussion of the desirability and effectiveness of laboratory work, and many experiments were conducted on the use of lecture-demonstrations. Examples of these experiments are given in articles by Anibal [2], Kiebler and Woody [3], Knox [4], and others. These studies are similar. They were made by comparing the achievement of two groups of pupils, one group taught by lecture-demonstration and

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[1] Rowland's thesis. op.cit.

[2] Comparative effectiveness of the lecture-demonstration and individual laboratory method. J.Ed.Res. 13:355, My '26.

[3] The individual laboratory vs. the lecture-demonstration method of teaching physics. J.Ed.Res. 7:50-8, Ja '23.

[4] The demonstration method versus the laboratory method of teaching high school chemistry. Sch.Rev. 35:376-86, My '27.

the other, acting as a control group, taught by the usual individual laboratory plan. Pupils are paired with those in the other group of equal I.Q.'s. Both groups are taught bythe same teacher, to eliminate teacher personality as a variable, and have identical subject-matter and usually identical class-room work. The total number of pupils used in these experiments varies from less than one hundred up to two or three hundred.

The results of these studies previous to 1928 have been thoroughly reviewed and criticized by H.W.Duel [5], who sums up their results as follows:

> "In general, the results of these studies indicate that,[6] so far as imparting information to the pupils is concerned, the lecture-demonstration method is superior to the laboratory method of procedure in immediate results, but retention of subject-matter, as shown be delayed tests, is better accomplished by the laboratory method. The difference between the methods, however, is not great in either case."

Duel goes on to describe his own experimental work on laboratory instruction. He distinguishes two types of laboratory work;

1. The even-front system, in which all pupils in the class perform the same experiment at the same time. Pupils are usually not allowed to start a new experiment in advance of other members of the class. The entire class is thus kept together, regardless of differences in individual ability and dexterity.

2. The rotation system, in which each pupil may proceed at his own rate, doing as many experiments as his ability and interest allow.

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[5] The even-front system vs. the rotation system in laboratory physics. Sch.Rev. 36:447-54, Je '28.

[6] Ibid, p 448.

Duel's study was made in the year 1925-26, in Minneapolis, to determine the relative effectiveness of these two methods. Pupils were paired by I.Q.'s. Teachers, recitation work, tests, and all other factors so far as possible were kept the same for both experimental and control groups. The rotation system was found to yield slightly superior results, both in quality and amount of work accomplished. The number of pupils used in this experiment was 168.

In contrast to the conclusions quoted from Duel above, Walter [7] describes an experiment which indicates that individual laboratory method of work is superior. He describes a laboratory course in which no printed directions are issued to the pupils. Each student is assigned a laboratory task, and he must determine the experimental methods to use, the apparatus required, etc. Walter's purpose is to develop habits of self-reliance and scientific thought. He places great importance on the attitude and trend of the pupil's thought while the experiment is being performed.

This question of individual laboratory versus lecture-demonstration method is still far from settled. The controversy has been summed up recently (1933) by Hazel [8], who apparently is sceptical about positive conclusions as to the superiority of any one method in general. After studying the published accounts of these experiments, I can share his scepticism.

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[7] Individual laboratory method of teaching physics when no printed directions are used. Sch.Sci.and Math. 30:429-31, Ap '30.

[8] High school laboratory work in physics. Sch.Sci.and Math. 33: 53-62, Ja '33.

> ". . . . there came upon us the storm of the question: [9] demonstration vs. individual laboratory method. The skies have hardly yet cleared away, and we hear occasionally the thunder of an article purporting to have clinching evidence one way or another. . . . A point which has not always been recognized . . . . is that an apparent superiority of one method over the other does not mean necessarily that one should replace the other in its entirety. I am certain that in our zeal for individual laboratory work following its introduction fifty years ago, we have carried into that phase of the work much material which properly belongs in the lecture-demonstration phase. This being the case we need a wiser distribution of materials between the two phases rather than an abandonment of one in favor of the other. One should remember that historically the lecture-demonstration method is much the older, that it has been tried thoroughly and that fifty years ago it was found desirable to give considerable emphasis to a supplementary approach through the individual laboratory method. In my judgment the pendulum has just now swung too far . . . . "

That method must be used with each pupil which is best fitted to enable him to reach his objectives. Different individuals learn in different ways. Some pupils learn most easily by doing, by actually manipulating apparatus themselves. Others learn best by reading, by being told, by watching apparatus manipulated by others. These individual differences are not necessarily indicated by the results of intelligence tests.

It is the present writer's opinion that most of the experimental work discussed above gives evidence of that old weakness of high school teachers,- the emphasis upon subject-matter at the expense of the pupil. The Physics laboratory, like every other school-room, should be a place for the teaching of children rather than Physics. The school must determine the best methods of instruction to use for each individual child. Whether individual laboratory or lecture-demonstration method is to be used must be determined by a study of the individual's thought

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[9] Sch.Sci.and Math. 33:53.

processes and study habits. This determination is perhaps properly a function of the exploratory and guidance programs in the junior high school. Educational guidance should determine what subjects should be studied, and, in this case at least, how they should be studied. No one method of instruction is equally good for all pupils.

CHAPTER VII.

MATHEMATICS IN HIGH SCHOOL PHYSICS.

The content of textbooks and courses in Physics has always been and still is largely of a mathematical nature, in that it deals with the quantitative aspect of nature. This is but natural, for Physics is one of the exact natural sciences, and has been created and developed with the aid of mathematics. Mathematics itself is simply logic applied to the exact treatment of quantitative problems. Physics as a purely qualitative or descriptive science is as inconceivable as a human body without bones. We can hardly hope, therefor, to teach a body of knowledge which can truly be called Physics, if we neglect entirely this quantitative aspect. This opinion is expressed by Warren:[1]

> "Physics is a study of relationships, and as such we cannot demathematize it completely. To do so would destroy the very framework of the subject matter structure. . . . since the laws and principles of physics can best be visualized and understood when real quantitative values of not too complex nature are introduced, I thoroughly believe in using mathematics as a tool for the purpose of greater clearness, and I do not find boys who know how to apply their algebra and geometry offering any objections. On the contrary I think they take pride in being able to 'figure out' an exact answer to a problem."

Mr. Warren goes on to state his belief that a one year course in merely the qualitative aspects of Physics could be made of considerable value to many students. The subject is so rich in materials that it can be of value to all pupils, irrespective of their ability or previous training in mathematics.

It is true, nevertheless, that the subject of Physics is distasteful to a majority of high school students because of its

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[1] To what extent shall secondary school physics be mathematical? Sch.Sci.and Math. 32:779-83, O '32.

mathematical treatment. LeSourd [2] apparently attributes to this fact the decreasing popularity of the subject. He quotes the results of a questionaire given by J.L.Tildsley in 1928 to high school students in New York City. Out of 3842 pupils answering it, 1128, or nearly thirty percent, stated that they received the least benefit from the mathematical aspect of Physics. No other aspect of the subject indicated nearly as large an unpopularity as this.

The problem of the mathematical content of Physics has apparently been investigated most thoroughly by W.R.Carter [3]. Taking Physics courses and textbooks as they are, he has attempted to evaluate the pupils' mathematical preparation, and to predict the pupils' success in Physics on that criterion. Carter recognizes two classes of mathematical abilities:

1. Ability to recognize certain mathematical concepts occurring in high school Physics.

2. Computational abilities, involving manipulation of mathematical symbols in arithmetical and algebraic processes.

To measure the first of these abilities Carter has developed an objective test, based upon analysis of the subject-matter of the three most commonly used textbooks. The following thirty-three concepts are included:

Negative number
Formula
Algebraic factor
Inequality
Direct proportion
Ratioo

Exponent
Limit
Identity
Area
Volume
Dimensions

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[2] To what extent shall secondary school physics be mathematical? Sch.Sci.and Math. 32:777-9, O '32.

[3] Study of certain mathematical abilities in high school physics. Math.Teach. 25:313-31, 388-419, 451-69, O-D '32.

Constant
Indirect measurement
Approximation in measurement
Perpendicular
Parallel
Minimum
Square root
Coefficient
Equation
Solution of an equation
A power
Maximum
Positive number
Graphic representation
Direction
Inverse proportion
Variation
Algebraic product
Algebraic numbers
Equality
Dependence

The Butler Test for Mathematical Concepts in Junior-High School Mathematics was also used to evaluate this ability.

The second class of abilities, of computational nature, were measured by the Kilzer-Kirby Inventory Test for the Mathematics Needed in High School Physics, Part I.

The Otis Self-Administering Tests of Mental Ability, Higher Examination, Form B, and the Nelson-Denny Reading Test completed the battery of five tests used by Carter in his research.

This battery was administered to 404 pupils, 274 boys and 130 girls, who were beginning the study of Physics. These pupils evidently formed a good sampling, considering the number of different schools and the wide range of individual differences represented. The results of these tests were correlated with the marks received by these pupils in the first semester of Physics. The correlations of these tests with the marks were as follows:[4]

Carter test	(mathematical concepts)	0.54
Butler "	" "	0.52
Kilzer-Kirby	(computation)	0.53
Otis	(mental ability)	0.53
Nelson-Denny	(reading ability)	0.45

Carter draws the following practical conclusions:

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[4] Math.Teach. 25:453, D '32.

> "Physics teaching as now conducted, however, apparently does not contribute to any appreciable extent to the pupil's ability to react to the quantitative aspects of the subject. . ."[5]

> "The importance of the computational abilities . . . . in relation to performance in physics seems to indicate that there is some justification for inclusion in the physics course of the exercises of computational nature which are now found in most physics textbooks."[6]

> ". . . . the fundamentals of mathematics are not thoroughly enough mastered by a large percentage of high school students to enable them to apply these fundamental processes in a field such as physics."[6]

L.R.Kilzer[7] made a careful investigation of the five most widely used textbooks to determine their mathematical content, and devised a test based on his findings. The test was first given to a representative sampling of Physics students in the high schools of Iowa, and the following conclusions were drawn from the results:[8]

> "1. The mathematics needed in solving the problems of high school physics involves a considerable body of information usually taught in arithmetic, algebra, and plane geometry. Not much trigonometry is needed.
>
> 2. Most of the mathematics needed in solving high school problems is not very difficult.
>
> 3. There is a definite need for maintenance drills covering the items and processes needed in physics.
>
> 4. Most pupils who are eligible to take high school physics use their mathematics poorly.
>
> 5. There is considerable difference in the preparation of individual pupils on certain items and processes. The difference in preparation of different schools is nearly as great.
>
> 6. The mathematics department should make sure that its pupils are well prepared and well drilled on the items of this test."

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[5] Math.Teach. 25:467, D '32.

[6] Ibid, p 468.

[7] The mathematics needed in high school physics. Sch.Sci.and Math. 29:360-2, Ap '29.

[8] Ibid, p 362.

Boston University
School of Education
Library

There are two possible sources of the mathematical difficulties in high school Physics:

1. The teaching of mathematics is at fault, in not equipping the pupils properly to apply their mathematics to Physics.

2. Too much and too difficult mathematics is involved in the Physics course.

The opinions and findings quoted above seem to indicate that the first hypothesis is the better substantiated one. Evidently Physics must contain a considerable amount of quantitative material. Evidently the Physics courses and textbooks in common use require no mathematical knowledge beyond that which the pupil should have obtained in the prerequisite courses. And, equally evidently, the mathematical courses have failed to develop in their pupils habits of quantitative thought and abilities of adapting their mathematical knowledge in one field to problems in another. This defect of mathematics teaching is not peculiar to high school. The present writer has observed in a considerable number of juniors in engineering colleges an inability to apply mathematical principles which they understood as mathematics to problems in applied science or engineering. Little transfer of training is obtained between logic in mathematics and logic in science.

The writer has for several years entertained the idea of teaching science together with the necessary mathematics as one subject. This idea is expressed by K.A.Zeller [9], when he emphasizes the importance of working out or deriving all the

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[9] Form and formula in physics teaching. Sch.Sci.and Math. 32: 433-7, Ap '32.

mathematical relationships, rather than merely giving them to be accepted on faith. Mathematics is of no importance to society in itself; it is a tool by which we can clarify our reasoning and solve our problems. Zeller states that mathematics is generally taught as though it stood for its own sake, without teaching how to use it. Noll[10] points out, in a previously cited article, that although transfer of training in habits of thought does occur, these habits are specific and should be developed specifically. It would seem that quantitative thinking and algebraic reasoning can be taught better by applying them to specific physical problems than by treating them as mathematical abstractions.

An experiment of this sort is being conducted by Teachers College, Columbia University, as reported by the National Survey of Secondary Education.[11]

> "At the Lincoln School, Teachers College, New York City, an experiment is under way through which geometry and physics are being taught together over a period of two years by a representative of each department. One year of the work has already been given to a class of 29 tenth grade pupils, and at the end of the second year it is thought possible that sufficient work may have been done to grant two units credit in mathematics and one in physics. In general, the classes meet six days per week, four of which are devoted to mathematics and two to physics."

No references are given to published reports of this experiment, and I have been unable to find any reports in current periodical literature.

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[10] T.C.Record. 35:209, Ap '32.

[11] U.S.Office of Ed.Bull.,1932, No.17. Monograph No.23. Instruction in mathematics. p 52.

The University of Chicago is also working on this problem of correlating science and mathematics, and the problem is discussed by E.R.Breslich of that institution.[12]

> "The nature of science and mathematics is favorable to correlation.- The present tendency in education to improve the results of teaching by integrating high school subjects should be of special interest to the teachers of science and mathematics. History shows that the union of the two fields has been an important influence in developing both."[13]

He goes on to review the question of mathematical deficiencies in pupils taking science courses and various suggested ways of dealing with the problem. He states two extreme methods:[14]

> "Various ways of dealing with the problem of mathematics and science have been recommended. One of the most drastic is to minimize or eliminate from science courses such phases of the sciences as can be taught well only by the use of mathematics. From the point of view of the learner the de-mathematizing of science courses is the wrong way of solving the problem. It widens the gap between two related fields. It moves in a direction opposite to that of the present trend toward integration.
>
> "Another extreme recommendation is to throw the responsibility for the mathematics needed in science entirely on the teacher of science. This is part of a general plan to abolish the formal teaching of high school mathematics and to let each subject provide for the mathematical needs of the pupils. This solution of the problem was seriously advocated several decades ago but failed to make any progress. However, it is being revived at the present time. It is sure to fail again. Only those who have attempted it know the hopelessness of the efforts of the teachers of science who try to teach factoring, the fundamental processes with fractions, or the solution of quadratic eqations to a class of pupils who are not thoroughly grounded in the elements of algebra. . . . The theory of letting each teacher teach the mathematics as they are needed in his course does not take these difficulties into account."

He goes on to describe the work being done at the University

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[12] Coordinating the activities of the departments of science and mathematics in secondary schools. Sch.Sci.and Math. 34:144-57, F '34.

[13] Ibid, pp 147-8.

[14] Ibid, p 154.

of Chicago High School in correlating general science and mathematics. The work extends over three grades. Five periods per week are allotted to it, divided between the mathematics and science departments. As far as possible, mathematical principles are taught before they are needed in science.

> "If any of the teachers are qualified to teach both subjects they should be given classes in both. However, there is no reason why the teaching could not be done by members of both departments."[15]

This work appears to resemble closely the experiment at the Lincoln School. Science and mathematics are still recognized as separate subjects. I have been able to find no descriptions of teaching experiments in which mathematics is developed only as needed for the solution of science problems. Breslich apparently considers it a hopelessly difficult task at the secondary level.

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[15] Sch.Sci.and Math. 34:156, F '34.

CHAPTER VIII.

TESTS AND MEASUREMENTS.

A large number of testing and measuring instruments are available for use in the field of high school Physics. Odell[1] remarked this in 1931, and several more tests have been published since then.

> "Physics ranks among those high school subjects in which[2] the supply of commercial tests is relatively good. At least one test in this subject was among the earliest tests constructed specifically for high school, and development since then has been fairly continuous, until today there are twenty or more tests or series of tests on the market. Some are of so little value that I shall omit them, but about half possess sufficient merit to be worth using on some occasion or other."

Physics, like every problem- or science-type subject, requires the use of several different types of tests.

1. Prognostic or aptitude tests, to determine the pupil's ability to learn and prgress in the subject.

2. Instructional tests, for use in showing the pupil his progress or achievement in the subject, and, sometimes, for motivating him or arousing his interest.

3. Diagnostic tests, to show the teacher what elements of the subject cause the pupil's learning difficulties, pointing the way to remedial teaching.

4. Achievement tests, to indicate whether the pupil has mastered the field tested. These tests may cover a part or the whole of the course. They may or may not be diagnostic. They are generally similar to instructional tests.

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[1] Standardized and other tests in physics. Ill.U.high school visitor's office. Proc.H.S.Conf. 1931. pp 292-6.

[2] Ibid, p 292.

5. Traditional forms of essay or discussion examinations. Although new-type or objective tests are extremely useful in all school subjects, they have a number of serious limitations. According to Symonds [3], they give the pupil no opportunity to show his ability in organizing his thought; they give no opportunity for making comparisons and explanations, or for formulating definitions; they are not diagnostic insofar as the pupil's reasoning processes are concerned. These limitations are removed by essay-type examinations, which, therefor, still have an important place in the testing program in Physics as well as in other subjects. Symonds recognizes this fact:

> "The traditional examination therefor has its merits and these are sufficient to guarantee its continued existence." [3]

And Odell voices the same opinion: [4]

> ". . . . My whole talk has dealt with commercial tests and new-type exercises with no attention to the traditional essay or discussion examination. I do not wish to leave the impression that I am in favor of abolishing it. I most decidedly am not, but I believe that it should be used under appropriate circumstances. . . . Any complete testing program should include at least three general types of measuring instruments: standardized tests, new-type tests made by the teacher, and discussion examinations likewise constructed by the teacher."

The most recent and most comprehensive discussion of new-type tests in Physics is that by W.W.Clark [5], a very valuable work for those who make use of these instruments. Clark's thesis describes the tests, gives illustrative samples of their material,

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[3] Measurement in secondary education. Macmillan, 1930. p 40.

[4] Ill.U. Proc.H.S.Conf. 1931. p 296.

[5] Use of new type or objective tests in physics. B.U.Graduate School thesis. 1933.

discusses reliability, validity, extent, and field of use.

I believe that the argument for objective testing programs has been convincingly presented by the large number of workers in that field, and needs no amplification here. This matter is discussed by L.N.Diamond [6], an experienced science teacher, and his contentions are representative of the entire argument. Diamond states that the old, and still used, system of grading students by percentage or letter marks, based upon the teacher's subjective judgment of essay examinations and reports, is vicious in that it forces competition among individual pupils and places grades above actual learning in importance. He recommends the use of objective tests, the results of which are to be held confidential by the teacher and pupil concerned. Each pupil will then be competing against his own record, rather than against other pupils. He believes, from his experience, that pupils enjoy new-type examinations or at least prefer them to the traditional type, and he recommends that pupil committees occasionally be entrusted with the duty of preparing tests for class use.

In Appendix A, page 72 below, I have listed all the published tests in Physics which I have been able to find. Most of these are to be found in the bibliography by Gertrude Hildreth [7]. Some others, not mentioned by her, are described in the thesis of Clark referred to above. Many of these tests are probably of little value, and some are now considered obsolete.

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[6] Roads to creative testing in high school science. Sch.Sci.and Math. 33:539-43, My '33.

[7] A bibliography of mental tests and rating scales. The Psychological Corp. N.Y. 1933.

A number of these tests consist largely or entirely of qhestions which can be answered only from memorized information. Such questions should obviously be used very sparingly in a science subject, the learning products of which should be reasoning ability and ability to apply fundamental principles, rather than memorized facts.

All of the better tests are based upon analytical study of the subject-matter content of the most widely used textbooks. Several tests are criticized because their elements are not proportioned among the several topics according to the make-up of texts.

Many of the published tests are not yet standardized. Some authors request that results of testing be returned, for the purpose of determining norms. Some tests are furnished with norms which were determined from a relatively small number of cases.

A number of test series are now available. These comprise aptitude, instructional, and final comprehensive tests, and constitute in effect a complete course outline. Among these series are the Michigan Instructional Tests, the Glenn-Osbourn Tests, Smith's Twentieth Century Practice Exercises, and Hurd's Work-Test Book. The Michigan Test, for example, consists of an initial test on physical information, necessary mathematics, and ability to read material in Physics texts understandingly, twenty-two instructional tests on selected units in Physics, and a final examination consisting of numerical problems and questions chosen at random from the unit tests. This series is standardized. Smith's test series includes twenty-eight units, but is not yet standardized.

Kirkpatrick and Greene have prepared a list of test elements or questions, from which a teacher may select to make up any number of tests. These elements are supposedly matched in difficulty.

A number of aptitude tests are available. These test the pupil's knowledge of mathematics and his ability to apply the mathematics to the type of problem encountered in Physics, and also frequently test his ability to read understandingly the sort of material found in Physics texts.

A number of tests are made up of questions designed to determine the pupil's ability to reason out the solution of a physical problem by applying his knowledge of fundamental principles. The new test by Black and Cushing, not yet off the press, (1933) promises to be an excellent instrument for this purpose.

It is evident that care must be used in selecting commercial tests for use in Physics teaching. The published books on testing are now so out of date that they do not include several valuable instruments. Publishers' lists must be used with discretion, since the making of tests is a competitive business. Before selecting and purchasing tests, one should determine specifically for what purpose they are to be used, and should then carefully study all available instruments.

CHAPTER IX.

CONCLUSIONS.

In the preceding chapters I have discussed present-day practices and ideas in the teaching of high school Physics, as determined by analysis of the literature dealing with this field during the last five years, from 1929 to 1934. This discussion has dealt with:

1. Enrollment or popularity trends in the subject.
2. A typical group of teachers of the subject, their education, experience, and other teaching duties.
3. The stated objectives of Physics courses.
4. Provision for individual differences.
5. Laboratory instruction.
6. Mathematics content of Physics courses.
7. Tests and measurements.

In this chapter I shall present my own views on the whole question of Physics in the high schools of the United States. These views are based largely upon the methods expounded by Professor G.M.Wilson of Boston University School of Education and Professor H.C.Morrison of the University of Chicago, and are highly colored by the educational philosophy of Ernest Butterfield, Commissioner of Education in the State of Connecticut.

Physics has always been offered chiefly for the purpose of satisfying college entrance requirements. The subject-matter and teaching methods were crystallized in the days when the American high school functioned chiefly as a college preparatory institution. The high school in these modern days is undergoing a vast

expansion. It is reaching out and extending its sphere of influence. At present it brings under its influence about one-half of all youth in this country between the ages of fourteen and eighteen, and the time is evidently soon to come when it will include this entire group of young people. Its traditional form and method are entirely unsuited to the needs of a large majority of these youth. The high school holds in its grasp a wonderful opportunity for benefitting our American society, but in order to realize its opportunity it must undergo a tremendous transformation in content, method, and underlying philosophy.

What is the place of physical science in this transformation? Our modern society has developed largely through man's tremendously increased understanding and control of nature. We have become highly technical and mechanized. The life of every person is profoundly influenced by the relatively small group of scientists and technicians. Science and engineering are vital elements in our culture, and they cannot be neglected in a program which aims to fit all our youth for their useful social lives.

I do not under-estimate the importance of the purely social studies in the secondary curriculum. I believe that the scope of secondary education can be divided broadly into two classes; man in society, and man in nature. "Man in society" deals with man-made institutions, government, religion, peace and war, history, politics,- the social studies. "Man in nature" deals with our knowledge of life, the structure of the world, the physical and mental needs of human beings,- the natural sciences, which we call Biology, Chemistry, Physics, and so on. These two classes are not isolated; they are intimately related, and this interrelationship

should be strongly emphasized in our educational program.

I do not intend the science program to develop all youth into full-fledged scientists, nor even embryonic ones. A few of these young people will possess the qualifications for scientific and technical vocations. It is the business of the exploratory and guidance program, among other functions, to discover the abilities of these individuals and to guide them towards a full development of their powers. The great majority of high school pupils will not and should not become scientists, but they must have some knowledge of the organization of the natural world and of man's efforts to use it for his own ends. They must develop habits of scientific thought, even if it be only open-mindedness, freedom from superstition, and a critical attitude toward all arguments. And they must be guided toward an appreciation of the importance and the limitations of science in modern society.

These objectives are general, and therefore somewhat vague. They form the foundation of a philosophy rather than a method. It has been my experience that the most important learning products are not gained during the progress of a formal education, but come to their full fruition only after the specific courses are completed, when one has had opportunity to reflect, to digest the subject-matter, and to apply some of it to the problems of his daily life. I hold, therefor, that a school course is successful when, and only when, it develops in the student an abiding interest and introduces him to sources from which he may derive materials for future informal education and growth. Courses must result in changed habits and attitudes if they are to be effective.

There will still be pupils in the high school who intend to continue their formal education in preparation for scientific or technical vocations. These pupils will probably continue to follow the subject-matter of the natural sciences as presented in the standard textbooks. Such a procedure is of questionable value, however, in view of the fact that colleges tend to reteach to freshman classes substantially the same material that is presented in the science courses of secondary schools. It is at least possible that these pupils would benefit more from a science curriculum patterned after the modern ideas which I am discussing.

It is not my purpose here to prepare the outline for a course in Physics embodying the new ideas in secondary education. Such a task is entirely outside the scope of a critical study. The preparation of a new course should be checked by extensive experimentation in actual class-room situations before any claims can be made for it. The new course must be a result of evolution.

In view of the great importance of science in modern culture, it seems advisable that every scondary school pupil receive a basic education in science. In the sense in which I use the word here, "education" fits Dr. Butterfield's whimsical definition, "what you remember after you have forgotten everything you learned." Education is that group of mental attitudes and habits which one retains as permanent adaptations of personality.

A science education of this sort demands a close coordination of the specific, distinct bodies of subject-matter presented in schools. We may establish a philosophy based upon general aims and lofty ideals, but the class-room teacher is faced with the practical

and difficult problems of choosing specific subject-matter and methods of presentation. The teacher must discuss, or lead the pupils to discuss, specific matters in the daily class meetings, must provide tasks for the pupils, must use the specific material found in textbooks and other sources of information. The subject-matter must be closely delimited.

The natural sciences are highly organized bodies of specific knowledge, and their organization has stood the test of time. We cannot, a priori, rewrite or reorganize their material. Such a reorganization must be a product of evolution, controlled and checked at every step. The secondary school can, however, set its entire science faculty to the task of coordinating the various courses in General Science, Chemistry, Biology, Physics, and Mathematics into a harmonious curriculum, graded to fit the interests and aptitudes of all pupils. This science curriculum should be coordinated with the social studies. An attempt to do this is indicated in the work of Jessie Clemensen noted above on page 32. A recent article by F.J.Weersing [1] discusses the question of coordination. He offers a general outline of a field called "the natural environment", consisting of correlated courses in general and specialized mathematics and natural science. The sequence has not yet been worked out, but the general aim is appreciation of scientific methods and the importance of science in the progress of civilization.

The subject of General Science has been very widely adopted in secondary schools. This subject evidently belongs in the junior-

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[1] A tentative plan for the reorganization of secondary school curricula. Calif.Q. of Sec.Ed. 9:157-66, Ja '34.

high level among other general courses, to serve as an exploratory experience for purposes of guidance. This course should serve to orient the pupil in science, to discover his aptitudes and interests, in order to make possible careful, intelligent planning of his further scientific education. It should not attempt to teach specific scientific knowledge of a factual type. It is doubtful whether even a beginning can be made here in developing habits of scientific thought.

The specific sciences, Chemistry, Physics, and Biology, belong in the senior-high school, and must be adaptable to the widely varying interests and aptitudes of all pupils. These subjects are all necessary for the full education of modern citizens.

The objectives of Physics, whatever the specific statements may be, are classifiable as either understandings or appreciations. The proper major techniques to use are thereforeproblem and appreciation. There should be no attempt to instill a mass of factual knowledge, or to develop automatic responses, except in the case of those few pupils who must be trained to satisfy requirements for entrance to certain other schools. By a system of individual instruction it is possible to prepare these few pupils properly, and at the same time accomplish the more general aims of science education.

There are two aspects of the teaching process; the individual, and the social. This idea has been developed and applied by Carleton Washburne [2] in his work at Winnetka. The Physics course must provide opportunities for each individual pupil to develop

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[2] Adjusting the school to the child. World Book Co. 1932.

his interests to the fullest extent allowed by his ability. This can be accomplished by permitting each pupil to work on problems chosen by him under the guidance of the teacher. Problems in Physics may vary from the construction of a radio receiver [3] to questions in home decoration involving the proper type and placing of electric lighting fixtures. Physics runs the gamut from the art of color and music to the technique of machine construction, and somewhere in this range there should be found problems to interest each pupil, which may serve to attain the objectives of scientific method of thought, understandings, and appreciations.

The individual does not live for himself alone; he lives, works, and plays, with others. The Physics class offers opportunities for socialization. Pupils having common interests may work in a group on the solution of a problem. Schemes of developing appreciations also offer opportunities for a community of effort.

In Appendix B, page 74 are given outlines of two units of work in Physics, illustrating the problem and appreciation techniques in social and individual work. These examples are more effective than description in making clear my ideas.

In order to conduct a Physics course of the sort considered her, the following elements are necessary;

1. Laboratory facilities.
2. Supervised study.
3. A library for sources of material.
4. Group meetings.

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[3] Curricular studies on the place of radio in school science and industrial arts. Sch.Sci.and Math. 26:181-8, 253-63, 361-71, 512-21, 592-608, F-Je '26.

5. The proper sort of teacher.

A laboratory is a place to work. For this Physics course it should be a sort of work-shop, equipped with tools and measuring instruments needed by the pupils. Expensive equipment is valuable for instructional purposes, but excellent results may be obtained with simple tools. A boy learns more about electrical principles in struggling to construct a crude but workable voltmeter than he does by using a fifty dollar commercial instrument to measure a potential in a carefully planned experiment. A girl learns more by experimenting with various types of home-made lamp shades than she does by measuring light intensity with a commercial luminometer. The mechanical advantage of levers is taught better by removing a boulder from the school grounds than it is by artificial apparatus in the class-room. These few examples give a picture of what I understand by a Physics laboratory in this new idea of education.

The traditional recitation is wasteful of time and often destructive to interest in Physics. When pupils are solving their own individual problems, the entire learning process becomes in a sense a laboratory procedure. The teacher should be available so far as possible to render advice and assistance. Too much teaching is done by telling the pupils, and the fine art of questioning is too often neglected. It is better to lead a pupil to solve his problem through skillful questioning than to lecture him thoroughly. Supervised study is an important method in the Dalton and Winnetka plans, and it is discussed in a number of the articles to which I have referred in this paper.

The Physics class-room or laboratory should have available a library containing reference textbooks, books on special subjects in Physics, scientific works of a popular nature, and periodicals such as "Scientific American", "Q.S.T.", "Radio Experimenter", "Popular Mechanics", and so on. A reference file or card catalog of important articles should be gradually built up. A scheme for doing this is suggested by D.R.Watson [4].

Frequent meetings should be held of the entire class or of interested groups, either for discussion or to hear talks by pupils or the teacher on important topics. Programs for these meetings should be arranged by the pupils themselves.

The type of teaching implied in this discussion requires that teachers be selected with great care. Extensive knowledge of Physics is necessary for successful teaching of the subject, but the teacher must have other qualities as well. He must himself have appreciation of science, and an understanding of its place in modern life, if he is to lead his pupils toward these objectives. He must be trained as a teacher, as well as a scientist. He must be in sympathy with his pupils. He must possess a high order of what we call social intelligence. Too frequently in the past high school teachers have been selected solely on the basis of their academic education, and high school teaching has suffered as a consequence.

What mathematics shall be used in the Physics course? The discussion on page 48 et.seq. above, shows that Physics is essentially quantitative and therefor mathematical. If the school

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[4] Supplementary material for the high school physics. Sch.Sci.and Math. 32:913-5, N '32.

can lead its pupils to realize this fact, it will have accomplished much. Quantitative thinking keeps one's feet on the ground; it tends to prevent wild notions of attaining impossible goals. "How much?" is a question which must be asked in nearly all the activities of life. Pupils should come to realize that mathematics is not merely a puzzle and intellectual torment, but a useful and most necessary tool for assuring the success of technical undertakings. They should achieve a clear conception of efficiency. The boy building a radio receiver should ask and answer the question, "Is it more economical to compute the value of this condenser or to determine its size by trial and error?" And if he decides to compute the value, he should be able to do it accurately. If certain pupils indicate a curiosity about the stresses in beams or the motions of a comet, I should not hesitate to guide them toward an understanding of Calculus sufficient to make them appreciate this most useful tool. The methods of solving some apparently unsolvable problems form a fascinating subject - for some people. Others would be thoroughly bored. The school's business is to stimulate interest and satisfy curiosity, and whatever detracts from these aims should be abolished.

How much and what kind of testing should be done in Physics? Tests of objective type are shown to be valuable for stimulating interest. If they do stimulate interest, use them. Pupils frequently wish to measure their knowledge and abilities, or compare themselves with others. Standard tests are useful for this purpose. In a Physics course of the sort I am proposing, with supervised study, group discussions, and programs arranged

by the pupils, there is no need of examinations to determine a pupil's achievement. The pupil is continually under observation. The teacher knows his ability, effort, and knowledge, thoroughly. The pupil himself knows the measure of his sttainments. School is a social instrument for guiding youth in their self-development, not for grading and classifying them and sorting out the unfit.

APPENDIX A.

PUBLISHED TESTING MATERIAL FOR PHYSICS.

1. Balderston's Elementary Physics. Philadelphia. Christopher Sower Co.
2. Caldwell's Science Tests - Physics. O.W.Caldwell. N.Y. General Board of Education. 1919.
3. Chapman Test in Electricity and Magnetism, Sound and Light. J.C.Chapman. Yale U. 1919.
4. Columbia Research Bureau Physics Tests. H.W.Farwell and B.D. Wood. World Book Co. 1926.
5. Cooperative Physics Test. N.Y.Coop Test Service. 1930, 1932.
6. Detroit Examination in Physics. Detroit Public Schools. 1927.
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APPENDIX B.

SAMPLE UNITS IN PHYSICS.

A PROBLEM UNIT.

Problem: Room X has poor acoustic properties. The voice of a person speaking in the front of the room is distorted and echoed so that it is very difficult to understand. What causes this and how can it be remedied?

This is a problem of practical nature, which might well attract the attention of pupils since it affects them directly. It would serve as a basis for the study of Sound, for such pupils in the class as happened to be interested.

The group of pupils interested in the problem would meet for discussion, to attempt a scientific formulation and analysis. They would discover the need for a knowledge of the physical nature of sound, and would proceed individually to study this subject from the reference books available.

Perhaps one week later, they meet again, and discuss the problem in the light of their new knowledge of Sound. They might then formulate a plan for research to determine the particular accoustic properties of Room X. Methods of doing this might involve extremely complicated and elaborate methods and instruments, quite beyond the technique of the pupils. Since every effort of the pupils should succeed to some extent, the teacher might be forced to use all his ingenuity to help them in arriving at some solution. If the school should be fortunate enough to possess radio amplifiers and an oscillograph, the work could be done quite thoroughly. Such equipment could be built by the pupils, but

would take time and money. However, the problem might well be turned in this direction; the learning products would be just as valuable.

In the absence of proper apparatus, the pupils would be forced to rely on bibliographical research to achieve a solution for their problem. If a large library is available, books such as Sabine's "American Architect" could be used. Architects in the community could be consulted. Experiments could be performed on the use of accoustic shields or screens made of cloth in the room.

The ideal result of this problem would be a practical, inexpensive solution, such as a false ceiling erected by the pupils with a school appropriation to cover the cost of materials.

AN APPRECIATION UNIT.

Dramatization of the development of the steam engine to be presented at a school assembly.

This unit might well be suggested by some pupils. Sketches of this sort are now quite common in radio programs. They are usually well done, instructive, and entertaining.

The group of pupils undertaking this job would organize themselves, plan the work, and appoint committees to care for the various details. The following committees would be needed:

Script committee, to prepare the dialogue.

Research committee, to dig into the subject-matter and make the plans historically accurate.

Property committee, to prepare stage properties.

Stage committee, to choose and train the actors.

These committees would necessarily be interdependent, furnishing

a valuable socialization experience.

The properties, if prepared by pupils clever with tools, might form a valuable permanent exhibit in the school museum; for example, a model of Watt's steam engine or Stevenson's valve gear.

A unit of this sort would be almost wholly the work of the pupils, with only the barest suggestion from the teacher. I merely suggest a possible outline of the finished production.

Scene I. James Watt in his mother's kitchen, watching the teakettle.

Scene II. Watt improves Newcomen's engine; the first steam engine to drive a cotton mill.

Scene III. Mill workers riot, and destroy the machinery.

Scene IV. Trevithick's locomotive and the first steam railway.

Scene V. Fulton's "Clermont" steams up the Hudson.

Scene VI. Parsons opens the throttle of his first steam turbine.

APPENDIX C.

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